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(54) Title: MULTICARRIER MODULATION

(57) Abstract

Multiple carriers are generated, modulated by data to be transmitted, as shown by oscillators (2-5) and modulators (21, 22, 31, 32, etc.) (or using Fourier transform techniques). They follow two paths. One path via adder (81) takes a set of carriers at integer multiples of a windowing frequency (f), where the odd carriers have some reference phase and the even carriers are in phase quadrature. The other path via adder (82) takes a second set of carriers, again at integer multiples of the windowing frequency; here the even carriers have the reference phase and the odd carriers are in phase quadrature. In the first path the signal is multiplied at (91) by a windowing function with a period equal to the reciprocal of the windowing frequency, whilst in the second path the signal is multiplied at (92) by a similar function which is time-shifted (by a delay 211) by half of the said period.
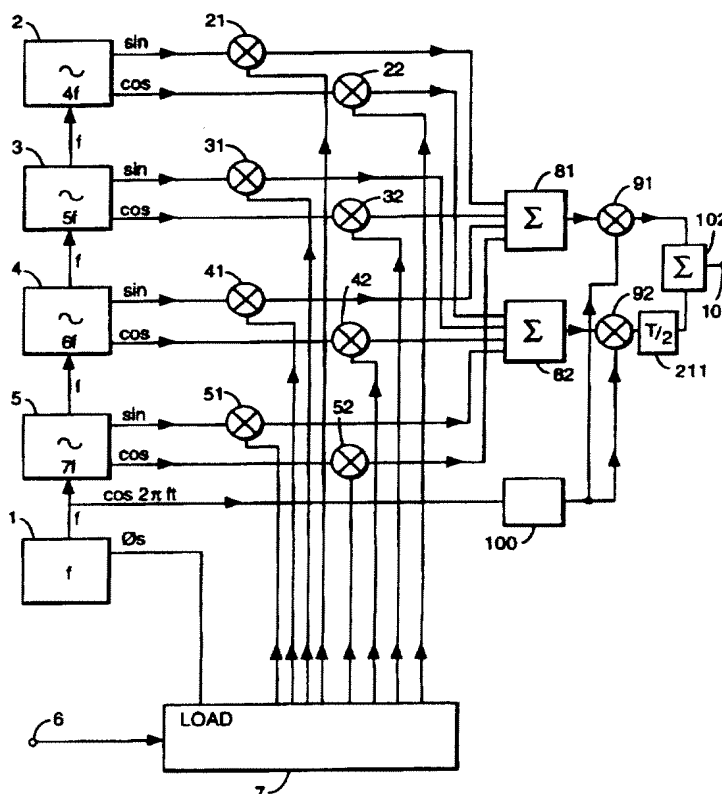
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MULTICARRIER MODULATION

This application is concerned with multicarrier modulation techniques, which serve to transport information over a communications channel by

5   modulating the information on a number of carriers, typically known as sub-channels.

Of particular interest are discrete systems where, rather than modulating a carrier with a continuously variable information signal, successive time periods ("symbols") of the carrier each service to transmit one piece of information; that,

10   is, the information does not vary during the course of a symbol.

Of the most practical interest is the situation where the information to be sent is in digital form, so that each symbol serves to transport a number of bits, but this is not in principle necessary and sampled analogue signal could be sent - i.e. the information signal is quantised in time but may or may not be quantised in

15   amplitude.

Quadrature modulation may if desired be used, where both the phase and amplitude of the carrier are varied, or (which amounts to the same thing) two carriers at the same frequency but in phase quadrature may each be modulated independently. A "multicarrier symbol" may thus consist of a time period during

20   which are transmitted (say) 256 carriers at different frequencies plus 256 carriers at the same set of frequencies but in phase quadrature. For digital transmission, up to 512 groups of bits may be modulated onto these carriers. Normally the carriers are harmonically related, being integer multiples of the symbol rate.
This form of modulation is particularly attractive for use on poor quality

25   transmission paths, since the number of bits allocated to each carrier can be tailored to the characteristics of the path, and indeed carriers may be omitted in parts of the frequency spectrum in which quality is especially poor.

The number of bits sent on each sub-channel may if desired be varied adaptively depending on the signal and noise levels in each sub-channel. This can

30   be a particular advantage for transmission paths which suffer cross talk or radio frequency interference, since the system can adapt automatically to avoid regions of frequency spectrum that are unsuitable for data transmission.

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Multicarrier modulation has been standardised for use on copper pair links in a form known as discrete multitone (DMT) modulation. This is described in the technical literature (see, e.g. "Multicarrier Modulation for Data Transmission: an Idea whose Time has come", J.A.C. Bingham, IEEE Comms. Magazine, May 1990,

5   pp. 5-14) and in a draft ANSI standard (T1E1.4/94-007) for asymmetrical digital subscriber loop technology. It is also of interest for use at higher rates than specified in the standard for use over shorter paths.

The systems referred to above may simply output successive symbols continuously to line, as illustrated in Figure 1A; the effect of the modulation on the

10   frequency spectrum of the output is that of a rectangular window and causes spreading (according to a sinc function) of the subchannel energy into the regions occupied by adjacent subchannels. However if the carriers are harmonically related to the reciprocal of the receiver's window durations the zero-crossings of the sinc function lie at the adjacent carrier frequencies and inter-subchannel

15   crosstalk is avoided.

Of concern with transmission by these type of modulation over cables such as twisted pair copper is the impact of narrowband interference, especially when using a large total bandwidth (e.g. up to 10 MHz). For example, cable terminations to domestic premises may collect interference from nearby amateur

20   radio stations (in the UK there are three amateur radio bands within the range 1 - 10 MHz). Of equal concern is the radiation of interference by the multicarrier transmission.

As mentioned earlier, these problems can be mitigated by not using those subchannels that are at frequencies known to lie within a band where problems of

25   this kind occur or are expected to occur. However the improvement obtained is limited because there will still be some radiation in the band from subchannels lying outside the band, due to the spreading referred to above, and similarly receivers decoding those adjacent channels have to pick up this energy and will thus pick up some interference from the band of concern. The sinc function

30   implies that the roll-off of amplitude as one moves away from the carrier is proportional to the reciprocal of the frequency offset.

One aim of the present invention, at least in its specific embodiments, is to alleviate this problem.

Aspects of the invention are set out in the claims.

Some embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 2 is a block diagram of a known transmitter;

5 Figure 3 is a block diagram of a transmitter according to one embodiment of the invention;

Figure 4 shows graphically some windowing waveforms used in the apparatus of Figure 3;

Figure 5 is a block diagram of a receiver for use with the transmitter of Figure 3;

10 Figure 6 illustrates a known transmitter using Fourier transform techniques; and

Figure 7 is a block diagram of a transmitter according to a second embodiment of the invention.

Multicarrier modulation systems can be achieved using a parallel bank of modulators (in the transmitter) or demodulators (at a receiver). Alternatively (and

15 preferably) modern digital signal processing techniques can be used by using an inverse fast Fourier transform to transform data to be transmitted from the frequency domain to the time domain. However the parallel method will be described first.

Figure 2 shows a transmitter for a conventional system having four

20 subchannels (though more would be used in practice). A clock generator 1 produces symbol rate pulses ϕ_s (Fig. 1B) at a frequency f (period T = 1/f) and also a reference sinusoidal output at this frequency (i.e. sin 2 πft), whilst four carrier oscillators 2-5 produce in-phase and quadrature carriers locked to the reference sinusoid at (e.g.) 4f, 5f, 6f and 7f: i.e.

25

$$\sin 8\pi ft \qquad \cos 8\pi ft$$
$$\sin 10\pi ft \qquad \cos 10\pi ft$$
$$\sin 12\pi ft \qquad \cos 12\pi ft$$
$$\sin 14\pi ft \qquad \cos 14\pi ft$$

30

All these nine signals are synchronous and could in practice be generated by a frequency synthesiser; separate oscillators are shown for clarity. Digital data to be transmitted are received at an input 6 and loaded into a register 7 under

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control of the symbol rate pulses ϕ_s so that a group of bits is available for the duration of one multicarrier symbol. The two outputs of each oscillator 2, 3, 4, 5 are connected to a pair of modulators 21, 22, 31, 32 etc. Each modulator is assumed to receive an allocated number of bits from the register 7 so that the

5   amplitude of its output is proportional to a digital value represented by those bits; however as mentioned earlier, they could equally well be fed with sampled analogue outputs.

The outputs of the eight modulators are added together in an adder 8 to form a multicarrier symbol and then pass to an output 10.

10   Although no window is explicitly applied, the fact that the data change at intervals of T means that implicitly the signal is divided into successive symbol periods by rectangular windows. We note that the frequency spectrum due to the rectangular window is

$$\frac{\sin(\pi \Delta f \tau)}{\pi \Delta f}$$ where τ is the duration of the window and Δf is the frequency

15   deviation from the nominal carrier frequency.

Figure 3 shows a transmitter according to a first embodiment of the invention. Again it has the clock generator 1 producing symbol pulses ϕs, the four oscillators 2-5, the eight modulators 21, 22, 31, 32 etc. the register 7 and output 10.

20   The first difference from Figure 2 is that a different window function is used.

This is a half cosine, i.e., referred to a time origin at the centre,

$$= \cos(\pi t/T) \qquad |t| < {}^T/_2$$
$$= 0 \qquad |t| > {}^T/_2$$

25   as shown in Figure 1C. Of course, this windowing function is generated repeatedly and may be expressed as

$$W = |\sin(\pi f t)| \qquad \text{with time measured from the beginning of the window.}$$

Note that it is not necessary that this is in phase with the carriers; it is however necessary that the "sin" carriers all have the same phase (or are in

30   antiphase) at the start of the window and that the "cos" carriers likewise have the same phase as one another at that point.

This shape of window function has a frequency spectrum of

5

$$\frac{T}{2}\left(\frac{\sin\pi(\Delta fT - 1/2)}{\pi(\Delta fT - 1/2)} + \frac{\sin\pi(\Delta fT + 1/2)}{\pi(\Delta fT + 1/2)}\right)$$

The window function is explicitly generated from the sinusoid by taking the modulus, e.g. with a full-wave rectifier 100.

Whist this has a broader central peak, it has a steeper roll-off as one
5 moves away from the carrier centre frequency.

Unfortunately, although this window improves the spectral characteristics of the signal, it results in crosstalk between individual subchannels within a symbol - e.g. between the modulated carriers at sin 8πft and sin 10πft.

We have found that this crosstalk can be alleviated by shifting the
10 windowing waveform applied to alternate sine carriers by a time T/2.

The same expedient of course also works for the cosine carriers, but to avoid crosstalk between (say) the sin 8πft and cos 10πft subchannels one proceeds as follows.

(a)   for carriers at frequencies which are an even multiple of the
15 fundamental f, the shifted window is applied to the cosine carriers only;

(b)   for carriers at frequencies which are an odd multiple of the fundamental f, the shifted window is applied to the sine carriers only.

This statement is also true if the words "odd" and "even" are switched.

Thus, in Figure 3, the outputs of the modulators 21, 32, 41, 42 are
20 supplied to a first adder 81 and the outputs of modulators 22, 31, 42, 51 are conducted to a second adder 82.

The output of the adder 81 is multiplied in a modulator 91 by the window function W, whilst the output of the adder 82 is multiplied in a modulator 92 by the window function W. The window function for the modulator 92 needs to be
25 delayed by T/2. In the arrangement in Figure 3, the relevant data also needs to be time shifted to align with the shifted window; also the carriers must be shifted to preserve the required phase relationship. Thus the output of the modulator 92 is delayed by T/2 (= 1/2f) in a delay line 101, thereby effectively delaying all three quantities. The outputs of the modulator 91 and the delay line 101 are added in
30 an adder 102 and the sum supplied to the output 10.

As a result of this process, the output obtained is the sum of eight components as shown in Figure 4 where we see eight window functions each

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marked with the frequency and phase of the carrier components modulated by them. Note that sin and cos in this Figure refer to time references at the start of one of the relevant windows; in a radio frequency system in which positive and negative frequencies are distinct all the carriers may be given an arbitrary phase

5   shift, provide that this is the same phase angle for each carrier.

The content of the generated signal may be expressed mathematically, for a generalised number of carriers, as:

$$\sum_{i=1}^{I} a(n_i) + \sum_{j=1}^{J} b(m_j)$$

10   where $a(n_i) = d_1.\ |sin(\pi ft)|.\ sin(2\pi n_i ft + \psi) + d_4.\ |cos(\pi ft)|.\ cos(2\pi n_i ft + \psi)$

$b(m_j) = d_3.\ |cos(\pi ft)|.\ sin(2\pi m_j ft + \psi) + d_2.\ |sin(\pi ft)|.\ cos(2\pi m_j ft + \psi)$

n_i $(i = 1,..I)$ are a set of mutually different odd positive integers

m_j $(j = 1,...J)$ are a set of mutually different even positive integers greater than unity.

15   f is a base frequency

ψ is a constant phase value

t is time

I is the number of carrier frequencies having a frequency which is an odd multiple of the base frequency f;

20   J is the number of carrier frequencies having a frequency which is an even multiple of the base frequency f;

d_1, d_2, d_3 and d_4 are values to be transmitted, where these data values may be different for different carrier frequencies and for different symbols, a symbol being the period between, for d_1 and d_2, consecutive zero values

25   of $sin(\pi ft)$ and, for d_3 and d_4, consecutive zero values of $cos(\pi ft)$.

Note however that some of these components may be omitted - e.g. all the cosine terms.

If preferred, the frequencies used may instead of being integer multiples of f, be subject to a frequency offset. Thus n_i and m_j in the above relations may be

30   replaced by $(n_i + \phi)$ and $(m_j + \phi)$ where ϕ is a constant shift value. In a radio frequency system where positive and negative frequencies are distinct, ϕ may take

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any value, but in baseband systems orthogonality will not be preserved unless $\phi = 0$ or $\phi = 1/2$.

m_i above is stated to be greater than unity; however, where $\phi = 0$, a d.c. term $d_5 |\sin \pi ft|$ or $d_5 |\cos \pi ft|$ (but not of course both) may also be added, where d_5 are data values which may be different for different symbols (a symbol being the period between consecutive zero values of $\sin \pi ft$ or of $\cos \pi ft$ respectively). When $\phi = 0$, ψ may have the value 0, $\pi/2$, π or $3\pi/2$.

Where $\phi = 1/2$. then the set m_i may include zero. ϕ may have the value $\pi/4$, $3\pi/4$, $5\pi/4$ or $7\pi/4$.

To obtain this offset in Figure 3, it is necessary simply that the oscillators generate the appropriate frequencies - e.g. $4\frac{1}{2}f$, $5\frac{1}{2}f$, $6\frac{1}{2}f$, $7\frac{1}{2}f$.

Figure 5 shows a suitable receiver for use with the transmitter of Figure 3. Signals received at an input 210 divide into two paths one of which is delayed in a delay line 211 by T/2; the delayed and undelayed signals are multiplied by the window function W identical to that at the transmitter, in multipliers 281, 282 respectively. Synchronous demodulators are formed by multipliers 221, 222, 231, etc. driven by oscillators 202 - 205 producing identical signals to the oscillators 2 - 5 at the transmitter. The connections from the multipliers 281, 282 are analogous to the corresponding connections at the transmitter, viz. the multiplier 281 feeds synchronous modulators 221, 232, 241, 252 whilst the multiplier 282 feeds synchronous demodulators 222, 231, 242, 251. The demodulated outputs are supplied to a register 207 whence they are available at an output 206. Units 200, 201, 211 perform the same function as units 100, 1, 101 at the transmitter; the clock generator 201 and oscillators 202 - 205 being locked to the incoming signal by conventional synchronisation arrangements (not shown).

Figure 6 shows a conventional multicarrier transmitter implementation using fast Fourier transform techniques. Data bits at an input 300 appear (with a new set of bits at intervals of T) at in a register 301 where a first group of bits I4 is considered to represent the in-phase or real component of a carrier at frequency 4f and a second group of bits to represent the quadrature or imaginary component Q4. Further such groups are labelled I5, Q5, I6, Q6, I7 and Q7 to indicate real and imaginary components of carriers at 5f, 6f and 7f. As mentioned above, normally there would be many more carriers than this. These bits are viewed as a

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frequency domain representation of the desired signal and processed in a processing unit 302 which applies the inverse FFT to produce an output consisting of digital signal samples representing the desired output waveform in the time domain, which are then converted into analogue form in a digital-to-analogue
5   converter 303 and fed to an output 304.

Figure 7 shows an FFT scheme according to a second embodiment of the present invention, in which the data input at 300 are divided between two registers 3011, 3012. The register 301 takes data bits only for the real components of the even carriers and for the quadrature components of the odd
10 carriers - i.e. I4, Q5, I6 and Q7. The other register fields Q4, I5, Q6 and I7 are permanently held at zero. These fields are fed to a first IFFT processor 3021 whose parallel signal outputs for one symbol are multiplied by coefficients (being the values of the window function W defined earlier) from a store 3051 in multipliers 3071 and these samples converted into serial form in a parallel-in serial-
15 out register (PISO) 3061.

A second register 3012 and IFFT unit 3022, with store 3052, PISO 3062, and multipliers 3072 are provided and operate in the same way except that only those input fields Q4, I5, Q6 and I7 which were held at zero now receive data bits, and the others I4, Q5, I6 and Q7 are now held at zero. The outputs of the two
20 PISO registers 3061,3062 are added together in an adder 308 after one (3061, as shown) has been delayed in a delay line 309 by T/2.

Although the above description of both the discrete and FFT versions have been described on the assumption that each modulating value (which, it may be noted, may assume both positive and negative values) may be represented by a
25 group of bits - or indeed a continuous function, it is possible to use only one bit for each. In this case the system may be realised as a bank of MSK (minimum shift keying) transmitters; provided however that transmitters running at frequencies which are odd multiples of the base frequency are run with carriers 90 degrees out of phase from the even ones.

30   Referring back to figure 3, it may be noted that the effect of the delay 101 may be realised by separate delays on the data, the carriers and the window function. This would have the advantage of permitting half the data to arrive later at the input register 7. Similar comments apply to the receiver of Figure 5.

In the transmitter of Figure 7, a frequency offset ϕ (as discussed in relation to Figure 3) can be provided by providing frequency changers at the outputs of the IFFT units 3021, 3022, for example by means of a multiplier receiving a complex output from the IFFT unit (only the real output being shown in Figure 7) and

5   multiplying by $(\cos 2\pi\phi ft + i \sin 2\pi\phi ft)$.

10

CLAIMS

1.   A method of transmitting signal values comprising generating an output signal which is the sum of:

5   (a)   the product of a first periodic window function and the sum of first carriers, at mutually different frequencies which differ from one another by even integer multiples of the window function frequency which is the reciprocal of the window function period and have a first phase, and second carriers, at mutually different frequencies which differ from one another by even integer multiples of

10   the window function frequency and differ from the first carriers by odd integer multiples of the window function frequency and are in phase quadrature to the first carriers;

(b)   the product of a second periodic window function and the sum of third carriers, at mutually different frequencies which differ from one another by

15   even integer multiples of the window function frequency and differ from the first carriers by odd integer multiples of the window function frequency and have the said first phase, and fourth carriers, at mutually different frequencies which differ from one another by even integer multiples of the window function frequency and differ from the first carriers by zero or by even integer multiples of the window

20   function frequency and are in phase quadrature to the first carriers; the second window function having the same frequency as the first window function but being shifted in time by half a window period; each carrier having, during a respective window period, an amplitude determined by a respective one of the signal values.

25

2.   A method of transmitting signal values comprising generating an output signal which is the sum of:

(a)   the product of a first periodic window function and the sum of first carriers, at mutually different frequencies which are even integer multiples of the

30   window function frequency and have a first phase;

(b)   the product of a second periodic window function and the sum of third carriers, at mutually different frequencies which are odd integer multiples of the window function frequency and have the said first phase; the second window

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function having the same frequency as the first window function but being shifted in time by half a window period; each carrier having, during a respective window period, an amplitude determined by a respective one of the signal values.

5   3.   A method of transmitting signal values comprising generating a multicarrier output signal

$$\sum_{i=1}^{I} a(n_i) + \sum_{j=1}^{J} b(m_j)$$

where

10   $a(n_i) = d_1 . |\sin(\pi ft)| . \sin(2\pi(n_i + \phi)ft + \psi) + d_4 . |\cos(\pi ft)| . \cos(2\pi(n_i + \phi)ft + \psi);$

$b(m_j) = d_3 . |\cos(\pi ft)| . \sin(2\pi(m_j + \phi)ft + \psi) + d_2 . |\sin(\pi ft)| . \cos(2\pi(m_j + \phi)ft + \psi);$

n_i (i = 1,..I) are a set of mutually different odd positive integers;

m_j (j = 1,..J) are a set of mutually different even positive integers;

f is a base frequency;

15   ϕ is a constant representing a frequency offset;

ψ is a constant phase value;

t is time;

I is the number of carrier frequencies having a frequency $(n_i + \phi)f$;

J is the number of carrier frequencies having a frequency $(m_j + \phi)f$;

20   d_1, d_2, d_3 and d_4 are values to be transmitted, where these data values may be different for different carrier frequencies and for different symbols, a symbol being the period between, for d_1 and d_2, consecutive zero values of $\sin(\pi ft)$ and, for d_3 and d_4 , consecutive zero values of $\cos(\pi ft)$.

25   4.   A method according to Claim 3 in which the frequency offset (ϕ) is zero.

5.   A method according to Claim 4 in which m_j are nonzero and the signal additionally includes a term $d_5 |\sin \pi ft|$ or $d_5 |\cos \pi ft|$, where d_5 are further values to be transmitted and may be different for different symbols, a symbol being the

30   period between consecutive zero values of $\sin \pi ft$ or of $\cos \pi ft$ respectively.

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6.   A method according to Claim 4 or 5 in which ψ is one of the values 0, π/2, π, 3π/2.

7.   A method according to Claim 3 in which the frequency offset (φ) is ½.

8.   A method according to Claim 7 in which the set m_j includes $m_j = 0$.

9.   A method according to Claim 7 or 8 in which ψ is one of the values π/4, 3π/4, 5π/4 or 7π/4.

10.   A method of transmitting signal values comprising generating a multicarrier output signal

$$\sum_{i=1}^{I} a(n_i) + \sum_{j=1}^{J} b(m_j)$$

where $a(n_i) = d(N_a (I + J) + i). |\sin (\pi ft)|. \sin (2\pi n_i ft + \psi)$

$b(m_j) = d(N_b (I + J) + I + j). |\cos (\pi ft|. \cos (2\pi m_j ft + \psi)$

n_i (i = 1,..I) are a set of odd positive integers greater than unity

m_j (j = 1,..J) are a set of even positive integers greater than unity.

f is a base frequency

t is time

I is the number of carriers having a frequency which is an odd multiple of the base frequency f;

J is the number of carriers having a frequency which is an even multiple of the base frequency f;

d(k) are a set of values to be transmitted; and

N_a and N_b are symbol numbers which are incremented at each zero value of respectively sin (πft) or cos(πft).

11.   An apparatus for transmitting signal values comprising:

(a) means for generating a signal having first frequency components and second frequency components, modulated by ones of the values, wherein

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(i) the first frequency components differ from one another by even integer multiples of a base frequency;

(ii) the first frequency components have a first phase;

(iii) the second frequency components differ from one another by even

5   integer multiples of the base frequency;

(iv) the second frequency components differ from the first components by odd integer multiples of the base frequency; and

(v) the second frequency components are in phase quadrature to the first frequency components;

10   (b)   means for generating a signal having third frequency components and fourth frequency components, modulated by ones of the values, wherein

(i) the third frequency components differ from one another by even integer multiples of a base frequency;

(ii) the third frequency components differ from the first components by

15   odd integer multiples of the base frequency;

(iii) the third frequency components have the first phase;

(iv) the fourth frequency components differ from one another by even integer multiples of the base frequency;

(v) the fourth frequency components differ from the first components by

20   zero or even integer multiples of the base frequency; and

(vi) the fourth frequency components are in phase quadrature to the first frequency components;

(c) means for multiplying the signal having the first and second frequency components by a first periodic window function which has a period equal to the

25   reciprocal of the base frequency;

(d) means for multiplying the signal having the third and fourth frequency components by a first periodic window function which has a period equal to the reciprocal of the base frequency and is time-shifted relative to the first window function by a delay equal to half of the said period; and

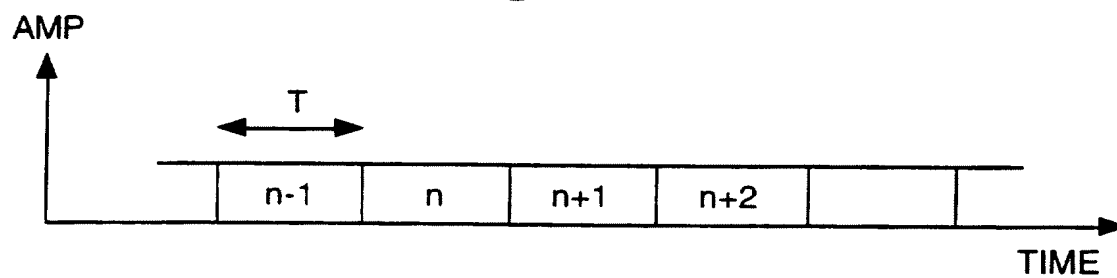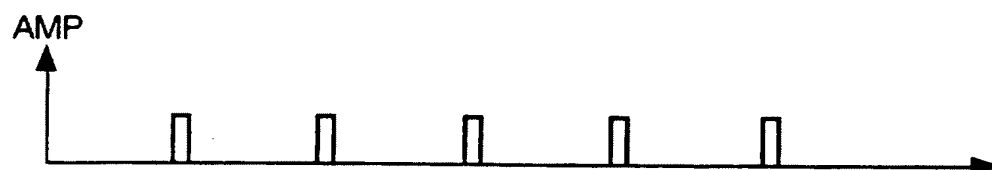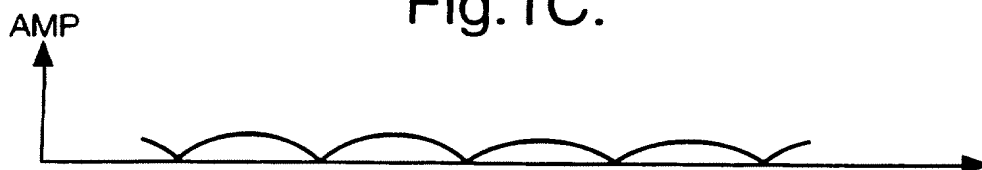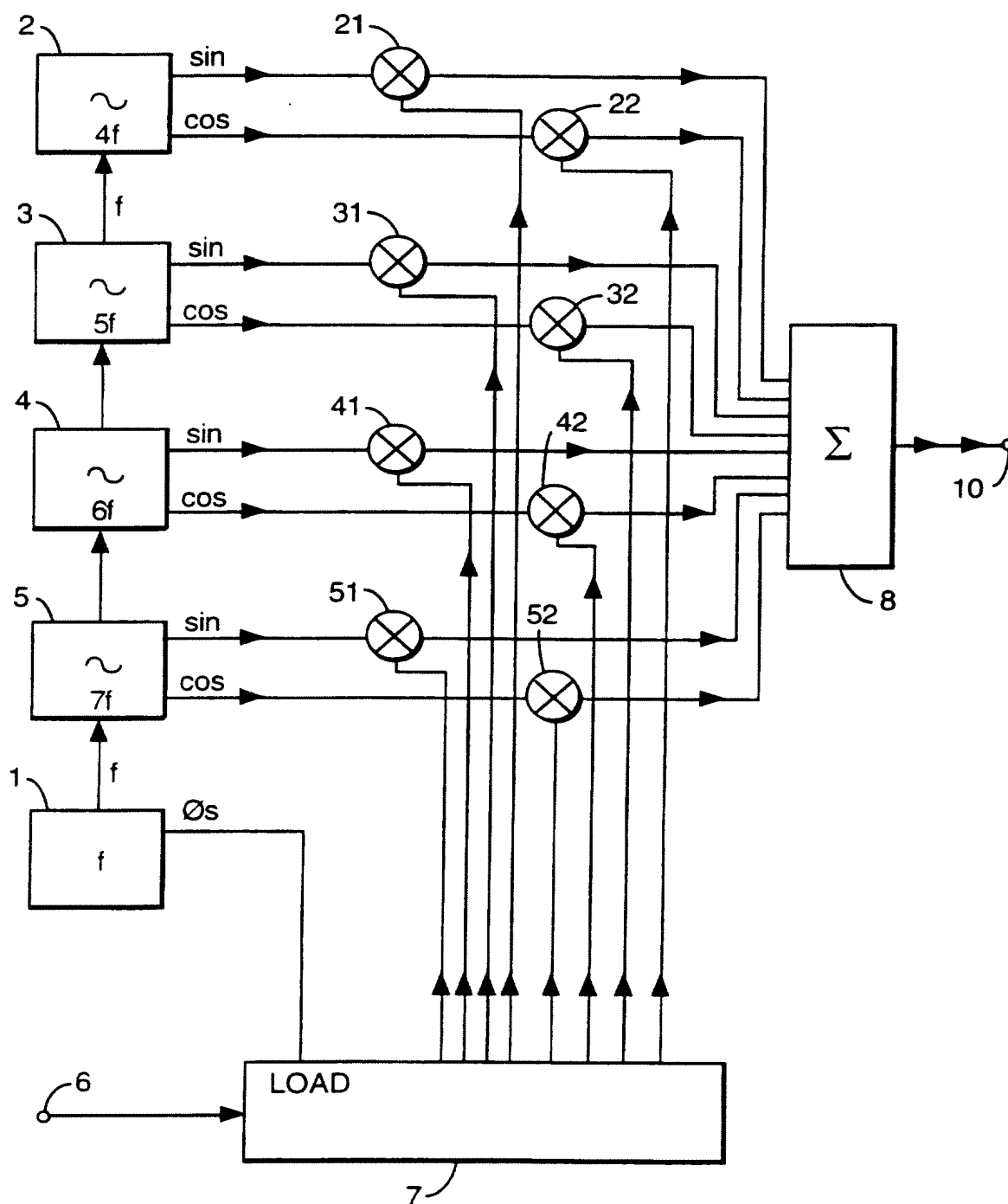30   (e) means for adding the outputs of the multiplying means.

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Fig.1A.
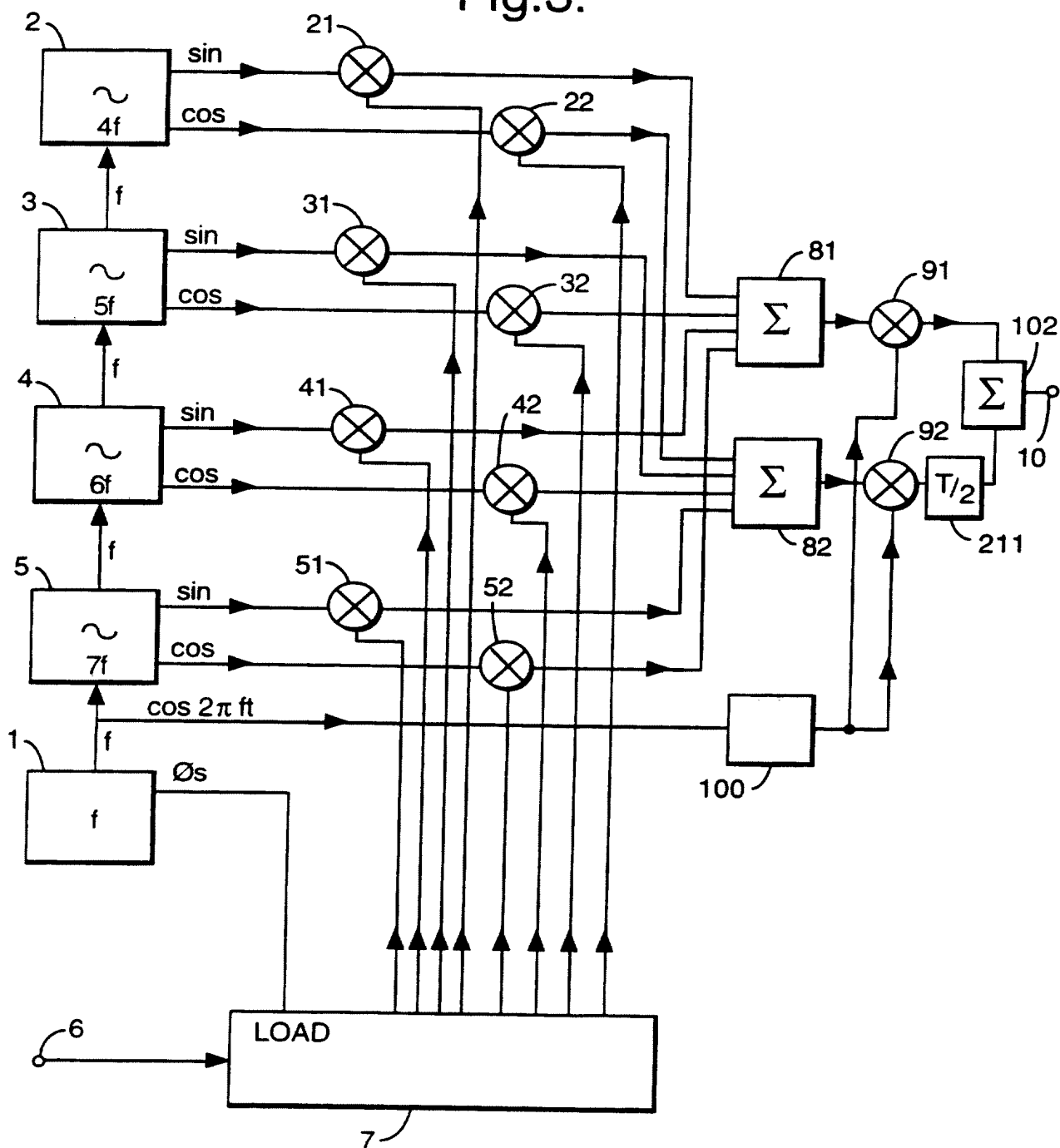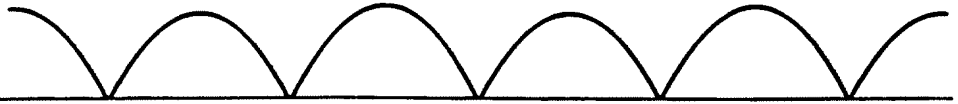
AMP

T

| | n-1 | n | n+1 | n+2 | | |

TIME

Fig.1B.

AMP

Fig.1C.

AMP

Fig.2.

Fig.3.

4/6

Fig.4.

sin (8πft)

cos (8πft)

sin (10πft)

cos (10πft)

sin (12πft)

cos (12πft)

sin (14πft)

cos (14πft)

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Fig.5.
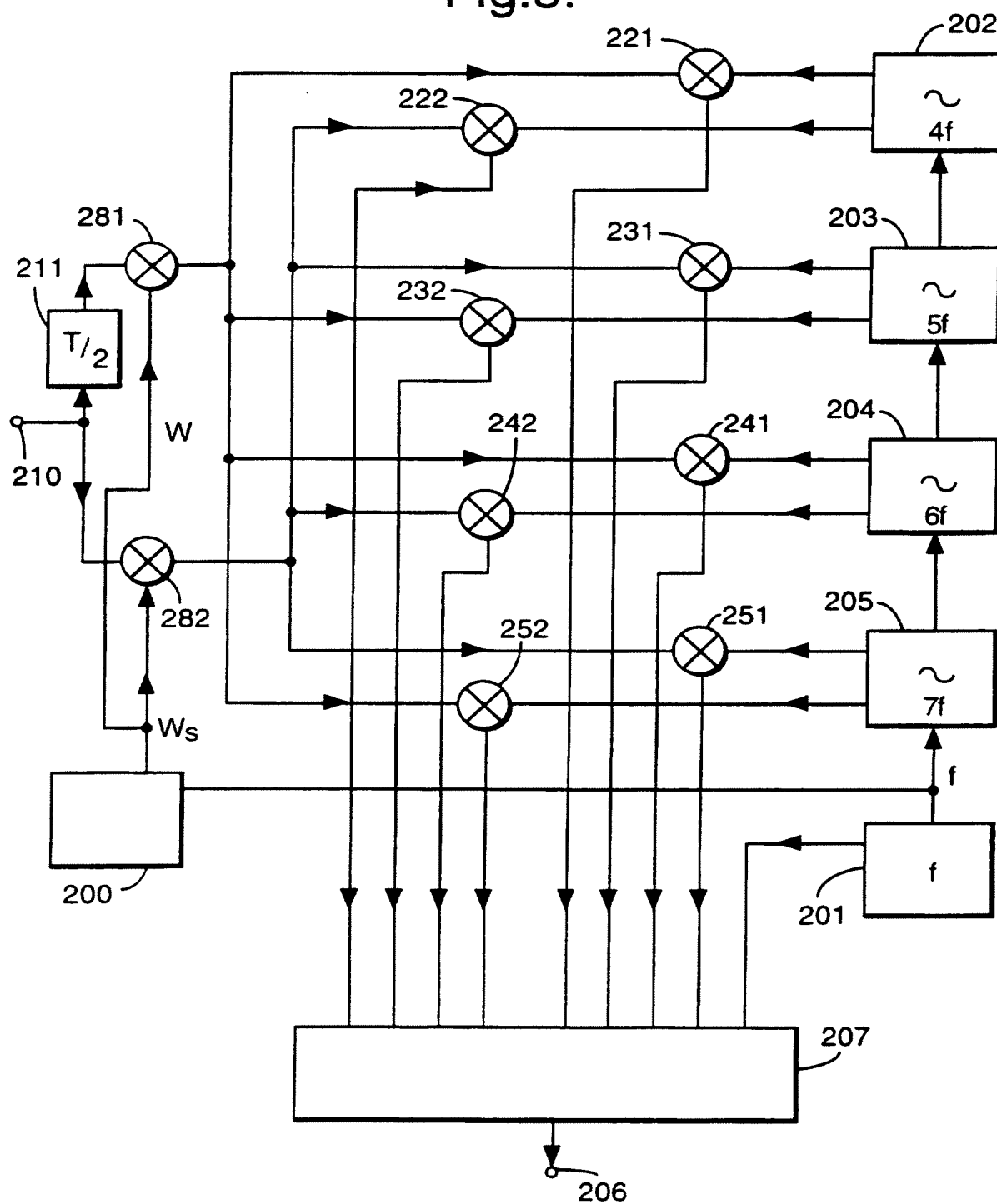
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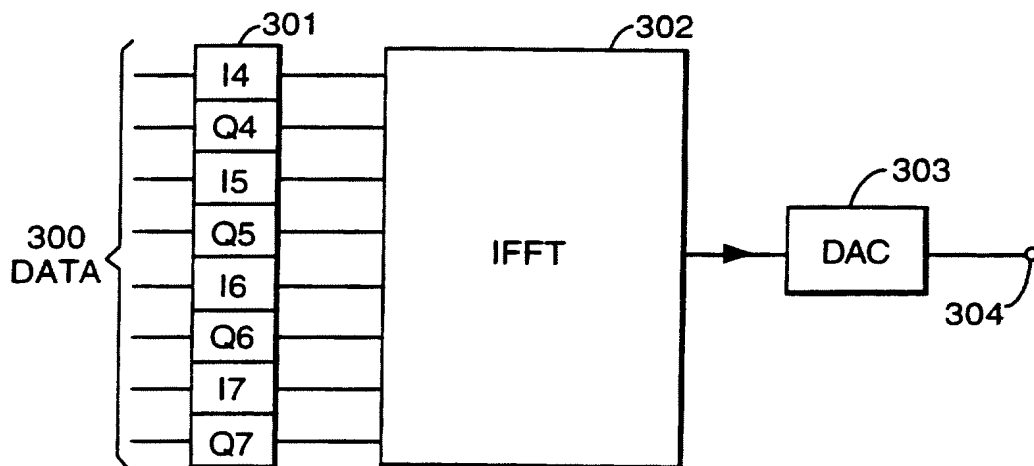
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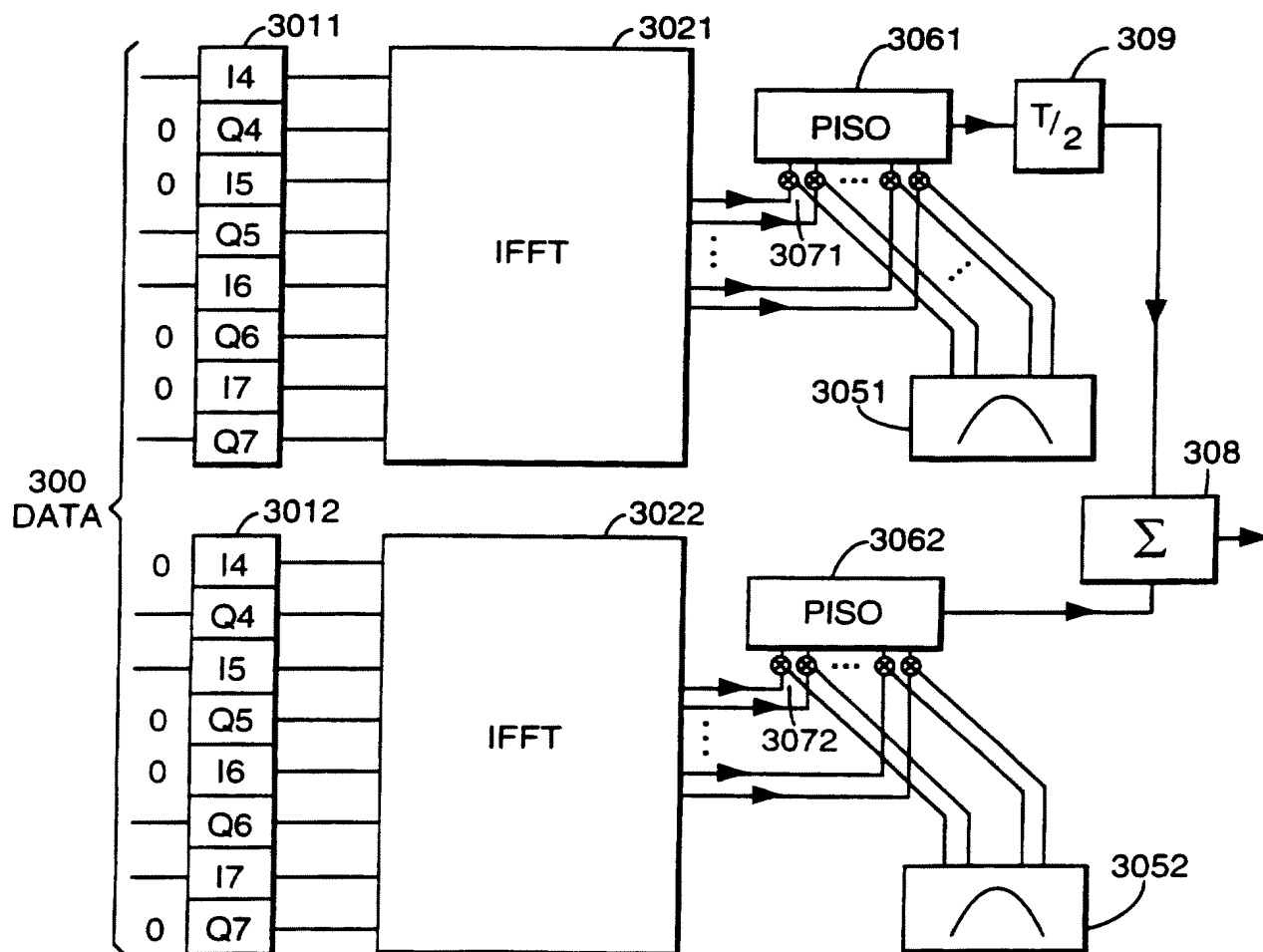
A. CLASSIFICATION OF SUBJECT MATTER

IPC 6   H04L27/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6   H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PROCEEDINGS OF THE INTERNTIONAL CONFERENCE ON COMMUNICATIONS, 18 - 22 June 1995, NEW YORK, US, pages 1695-1699, XP000535043 LI & STETTE: "Waveform shaped MCM for digital microwave radio" see page 1695, left-hand column, paragraph 1 - paragraph 2 see page 1695, right-hand column, paragraph 3 - paragraph 4 --- -/--	1-11

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 January 1997	1 3. 02. 97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax (+ 31-70) 340-3016	Scriven, P

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EUROPEAN TRANSACTIONS ON TELECOMMUNICATIONS AND RELATED TECHNOLOGIES, vol. 3, no. 3, MILANO IT, pages 255-264, XP000304924 FLIEGE: "Orthogonal multiple carrier data transmission" see figures 1,2 see page 259, left-hand column, paragraph 4 - page 260, right-hand column, paragraph 3; figures 7-11	1-11
A	EP 0 613 267 A (PHILIPS) 31 August 1994 see abstract; figures 1,2 see column 2, line 58 - column 3, line 12 see column 4, line 18 - line 24	1-11
A	EP 0 441 732 A (ETAT FRANÇAIS) 14 August 1991 see abstract; figure 3	1-11
A	EP 0 499 560 A (FRANCE TELECOM) 19 August 1992 see abstract	1-11
A	44TH IEEE VEHICULAR TECHNOLOGY CONFERENCE, 8 - 10 June 1994, STOCKHOM, SE, pages 1542-1546, XP000497680 GÜNTHER & HABERMANN: "DOQPSK-differential demodulation of filtered offset QPSK" see page 1542, left-hand column, paragraph 2	1-11
X,P	WO 96 13918 A (AIRNET COMMUNICATIONS) 9 May 1996 see abstract; figure 1 see page 3, line 15 - line 30 see page 5, line 1 - line 14	3-9

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INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 96/02445

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